

Influence of alloy disorder scattering on drift velocity of hot electrons at low temperature under magnetic quantization in n-Hg_{0.8}Cd_{0.2}Te

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Abstract : The drift velocity of hot electrons in n-Hg_{0.8}Cd_{0.2}Te has been calculated in the presence of parallel electric and quantizing magnetic fields at low temperatures. The low temperature scattering mechanisms such as acoustic phonon scattering via deformation potential, piezoelectric coupling, ionized impurity and alloy disorder scattering are considered. The effect of high electric field leading to a disturbance in the phonon distribution has also been incorporated. The effect of alloy disorder scattering on the drift velocity has been analysed for equilibrium and disturbed phonon distributions.

Keywords : Hot electron, drift velocity, alloy disorder scattering

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1. Introduction

Mercury Cadmium Telluride is one of the important materials widely investigated by many workers due to various reasons. Firstly, the material offers an excellent choice for an infrared detector useful for operating in atmospheric window region. Secondly it being a narrow-gap semiconductor with small effective mass, magnetic quantization condition can easily be achieved in this material with reasonably low magnetic field.

Transport properties in n-Hg_{0.8}Cd_{0.2}Te at low temperatures are governed by acoustic phonon and alloy disorder scattering. The recent analysis of mobility in the extreme quantum limit (EQL) [1] shows that the alloy disorder scattering is one of the dominant mechanism in determining the mobility at low temperatures.

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Furthermore the hot electron transport is also an important aspect to be investigated as far as device applications are concerned. In $n\text{-Hg}_{0.8}\text{Cd}_{0.2}\text{Te}$, high field transport *i.e.* energy loss rate and drift velocity of hot electrons have been investigated theoretically and experimentally by many authors [2–5]. However, the effect of alloy disorder scattering on the high field quantum magnetotransport properties has not being investigated in detail. It will be interesting to study the influence of alloy disorder scattering on drift velocity of hot electrons in $n\text{-HgCdTe}$ in the presence of a quantizing magnetic field. Such investigation is useful in understanding the specific role of the alloy disorder scattering and its influence on high field transport in the presence of quantizing magnetic field which is quite different from hot electron transport without magnetic field.

In the present paper, the drift velocity has been investigated under high field condition in the presence of a quantizing magnetic field (longitudinal configuration). The dominant scattering mechanisms are acoustic phonon *via* deformation potential and piezoelectric coupling, ionized impurity scattering and alloy disorder scattering. Furthermore, the equilibrium phonon distribution function which obeys Bose-Einstein distribution is assumed to be disturbed due to the presence of high electric field. This is because the carriers supply the energy obtained from the applied electric field to the phonons at much higher rate compared to the rate at which phonons lose excess energy to the thermal bath and it has a feedback effect causing a change in the energy loss rate of the hot electrons. In calculating the drift velocity, carriers are confined to the lowest Landau level (EQL) and obey displaced Maxwellian distributions [6]. The nonparabolicity of the band structure, modified free carriers screening due to high magnetic field and nonequipartition of phonons are also considered.

Finally, the influence of alloy disorder scattering on the longitudinal drift velocity of hot electrons are being examined for equilibrium and disturbed nonequilibrium phonon distributions.

2. Theory

Assuming that the electric field is applied to a semiconductor with a nonparabolic band structure [7] in the same direction as in the high magnetic field B and taking a Maxwell Boltzman distribution for carriers occupying the lowest Landau level characterised by an electron temperature T_e , the drift velocity of electron can be obtained from the relation

$$v_d = \mu \mathcal{E} \quad (1)$$

At the steady condition, energy loss rate can be written as a function of electric field as

$$\langle dE/dT \rangle = v_d \mu \mathcal{E} \quad (2)$$

Again the mobility is given by

$$\mu = e\langle\tau\rangle/m^* \quad (3)$$

where $\langle\tau\rangle$ is the average momentum relaxation time.

The momentum relaxation times needed in the equation (3) for computing the drift velocity are taken for elastic phonon scattering, piezoelectric coupling, ionized impurity and alloy disorder scattering. Then the combined effects of relaxation times can be expressed as

$$1/\tau = 1/\tau_{\text{ac}} + 1/\tau_{\text{pz}} + 1/\tau_{\text{alloy}} + 1/\tau_{\text{imp}} \quad (4)$$

The explicit τ 's are obtained from [8] including the magnetic field dependent screening, non equipartition of phonon and Landau level broadening.

Furthermore, the average energy loss rate has been obtained assuming elastic acoustic phonon via deformation potential and piezo electric coupling which have the dominant loss scattering mechanism at low temperature. The alloy disorder scattering being an elastic scattering does not affect the energy loss rate while its contributions to the combined relaxation time is quite important. Also the calculation of energy loss rate includes magnetic field dependent screening and Landau level broadening and non equipartition of phonons [3].

In obtaining the drift velocity we consider (a) the phonon distribution which is independent of magnetic field given by Bose Einstein distribution, (b) phonon distribution which is given by the following rate equation [3]

$$(dN_R/dT)_e = (N_R - N_0)/\tau_p \quad (5)$$

The ultimate phonon distribution as a function of electric field can be obtained by the solution of the rate equation (5).

Finally, the drift velocity for cases (a) and (b) with the inclusion of all scattering mechanisms are discussed.

3. Results and discussions

The longitudinal drift velocities of hot electrons in n-Hg_{0.8}Cd_{0.2}Te are calculated as a function of electron temperatures ranging from 12 K to 40 K at a lattice temperature $T_L = 10$ K and magnetic field $B = 4$ T. Variation of drift velocity with electron temperature is studied for all scattering mechanisms. A comparison of the results both for equilibrium and nonequilibrium phonon distributions with phonon life times $\tau_p = 100$ ns and $\tau_p = 1000$ ns is also done here.

Phonon life time at low temperature is assumed to be governed by the phonon boundary scattering which is given by $\tau = l/v$ where l is the dimension of the sample and v is the acoustic velocity. The other nonelectronic phonon mechanisms responsible for

phonon annihilation is phonon-phonon *etc.* These effects are dominant at high temperature only [9,10].

Figure 1 shows that drift velocity increases with electron temperature, but the rate of increase slows down in the higher electron temperature. It is seen that the inclusion of

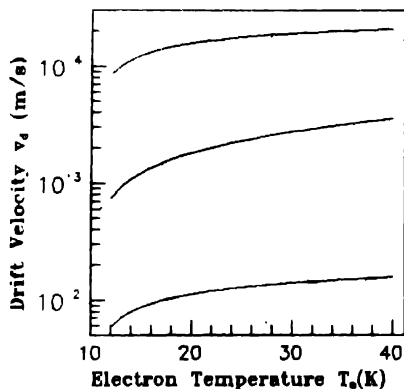


Figure 1. Variation of drift velocity of hot electron in $n\text{-Hg}_{0.8}\text{Cd}_{0.2}\text{Te}$ for different scattering mechanisms as a function of electron temperature. The upper curve for the acoustic phonon via deformation potential and piezoelectric coupling, the middle curve for ionized impurity scattering and the lower curve for alloy disorder scattering.

ionized impurity scattering decreases the drift velocity value but the alloy scattering reduces the magnitude of drift velocity quite significantly.

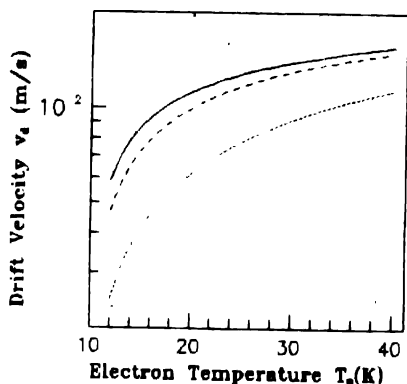


Figure 2. Variation of drift velocity of hot electron in $n\text{-Hg}_{0.8}\text{Cd}_{0.2}\text{Te}$ for all scattering mechanisms as a function of electron temperature for equilibrium (solid) and nonequilibrium phonon distributions (dashed curve for $\tau_p = 100$ ns and dotted curve for $\tau_p = 1000$ ns).

Now the energy loss rate at low temperature due to acoustic and piezoelectric phonon scattering increases with electron temperature and so drift velocity also increases with electron temperature. But when ionized impurity and alloy disorder scattering are considered, the drift velocity decreases because of the enhancement of scattering rate. The low temperature high field drift velocity is primarily determined by the momentum relaxation time of nonphonon type of scattering such as alloy disorder scattering because the effect of electron temperature on drift velocity is not so significant due to small energy loss rate when acoustic phonon scattering is considered. As a result alloy scattering plays dominant role at low temperature and decrease the value of drift velocity significantly.

In Figure 2, a nonequilibrium phonon effect is considered. The energy loss rate process which is due to acoustic and piezoelectric scattering, the nonphonon ionized impurity and alloy disorder scattering is not affected by the non equilibrium phonon distributions. It is clear from the nature of the graph that the value of drift velocity for non equilibrium phonon distributions is lower than that of equilibrium phonons. Actually the inclusion of non equilibrium phonons slows down the cooling processes due to reabsorption of phonons emitted by hot electrons [3]. This process may be considered as a feedback process which leads to decrease in energy loss rate and as a result value of drift velocity is also decreased for nonequilibrium phonon distributions.

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